

SILICONE CONTACT ADHESIVE WITH REDUCED COLD FLOW

The invention relates to reagents for cross-linking pressure-sensitive adhesive formulations on the basis of silicone polymers.

Apart from other technical applications, such pressure-sensitive adhesive formulations are mainly employed in the manufacture of medicinal patches. Among the medicinal patches, these silicone pressure-sensitive adhesives which are cross-linked in a novel manner are especially suited for the production of active substance-containing medicinal patches, i.e. of transdermal therapeutic systems (TTS).

The described cross-linking reagents are employed according to the invention in the solvent-containing coating and drying of pressure-sensitive silicone adhesive formulations.

It is only under these conditions that the reagents develop their cross-linking action, which results in the formation of a three-dimensional polymer network.

The resultant pressure-sensitive adhesive layers thereby lose their flowability - their so-called "cold flow".

Cold flow is an undesirable phenomenon because when it occurs, two surfaces bonded to each other by a pressure-sensitive adhesive layer can be displaced relative to each other even under the influence of gravity, so that a position-constant bond between these surfaces cannot be ensured.

In the case of TTS, this problem especially concerns the adhesive bonding of the system to the application site on

humans or animals. Furthermore, when cold flow sets in within the silicone adhesive layer comprised in the TTS, the influence of gravity and of cohesion and adhesion forces can result in undesirable deformation and shifting within the system even during storage.

It has now surprisingly been found that the cross-linking reagents employed in the cross-linking of polyacrylate-based pressure-sensitive adhesives can also be successfully used with silicone polymers, despite the fact that the chemical properties of said silicone polymers are fundamentally different from those of polyacrylates.

Organometallic complexes of certain metal cations have proved to be especially effective. Among these, complexes of metals such as aluminum, titanium, zirconium or zinc are particularly preferred according to the invention. As an organic complex former, acetylacetone is particularly suited for medical application.

The cross-linking reagents are added to the solution of the silicone pressure-sensitive adhesive and develop their cross-linking action only after the solvents or stabilizing additives have been removed by drying.

Pressure-sensitive adhesives based on silicone polymers are of particular significance in medical application. This is due to their excellent dermatological compatibility with regard to the triggering of skin irritations and immunological reactions (sensibilization, allergization). In addition, silicone pressure-sensitive adhesives are products which adhere to human skin reliably and over a longer period of time, up to several days. Their strongly water-repellent nature also plays a role in this context.

In the TTS field, silicone pressure-sensitive adhesives stand out for their good chemical compatibility with phar-

maceutical active agents and auxiliary substances, which promotes the chemical stability and storability of products based on said adhesives. The unusually high permeability (diffusibility) of the silicone polymers, which facilitates the release of contained active and auxiliary agents, is also of particular significance.

Besides these advantages, the silicone pressure-sensitive adhesives available on the market for medicinal application (e.g. product line Bio-PSA Q7 by Dow Corning Company) show considerable deficits as regards their rheological properties.

These products are polysiloxane-based polymers exhibiting no three-dimensional cross-linking or only one limited to microscopic areas. They have a structure that is substantially threadlike and branched to only a small extent or not at all.

This is necessary so that the products can be dissolved at all in organic solvents such as e.g. short-chain alkanes (heptane, petrol) or ethyl acetate, and so that they can be subjected to solvent-containing processing.

Furthermore, these prior art polymers are one-component polymer solutions.

One-component means that the polymers contained in the solution are not intended, in their further processing, for a two-component reaction in the known sense of resin and hardener.

One-component does not, however, mean that the solution may not contain more than one type of polysiloxane polymer, optionally also in admixture with chemically different polymers (e.g. polyacrylates).

The procedures employed in the processing of one-component polysiloxane pressure-sensitive solutions described in the following must not be confused with those procedures and catalysts that have been described in manifold ways for two-component silicone adhesives. Such systems contain at least two different types of polysiloxanes which are intended, during their further processing, for a reaction yielding a three-dimensional polymer network in the sense of resin and hardener.

The term polysiloxane also comprises mixed polymers of polysiloxane to whose polymer chains chemically different sections, for example on the basis of polyethylene oxide, polypropylene oxide, polyvinyl pyrrolidone or poly(meth)acrylate, are incorporated or added.

In the field of TTS production, the processing of polysiloxane pressure-sensitive adhesive solutions comprises spreading and drying to form thin, pressure-sensitive polymer films.

In the processed state, the lack of three-dimensional cross-linking proves a disadvantage, as the threadlike polymer chains retain a certain flowability, even if an extremely slow one. This is referred to as "cold flow" by the experts since it occurs even at room temperature.

The following forces can all promote such a flow:

1. gravity
2. all mechanical forces that may have an effect on the product during production or storage,
3. adhesion forces between the pressure-sensitive polymers and the surfaces they cover (resulting in contraction or spreading)
4. cohesion forces in the polymer itself (contraction).

Cold flow practically always has disadvantageous effects during the storage of TTS, which may typically be for a period of two years or more. In this way, e.g. conglutination of the products with their packages may result.

The phenomenon also undesirably arises upon application to the human or animal skin, especially promoted by the warm body temperature. When the TTS is worn for several hours or days, the result may be a displacement thereof caused by the TTS practically flowing over the skin. Furthermore, the silicone pressure-sensitive adhesive may spread on the skin by slowly flowing beyond the area originally provided with adhesive. This frequently leads to residue remaining on the skin along the marginal area of the system after removal of the system. This residue is regarded as extremely annoying by the user.

The problem of cold flow in silicone pressure-sensitive adhesives is known. US 5,232,702 describes a large number of possible countermeasures. The document mentions various types of fillers and additives; however, none of these is described as a cross-linking reagent.

In connection with active-substance systems, cross-linking reactions are even expressly described as being problematic or impossible because the required temperatures are too high or because of a lacking biocompatibility of the reagents (column 5, lines 3-10).

A great number of other cohesion-enhancing measures are described instead.

As these measures do not, in practice, always enable the control of the problem, it was the object of the invention to provide novel and more efficient methods for suppressing cold flow in silicone pressure-sensitive adhesives.

This object is surprisingly achieved by adding reagents which are employed for the suppression of cold flow in a chemically completely different family of pressure-sensitive adhesive polymers, namely polyacrylates.

This transferred applicability was not to be expected since polysiloxanes, as the skeletal structure of silicone polymers, are of a completely different chemical nature than polyacrylates, which are built up of pure hydrocarbon chemistry.

It is known to those skilled in the art that with polyacrylate pressure-sensitive adhesives containing free carboxyl or hydroxyl groups bound to the polymer, it is possible to attain three-dimensional cross-linking of polymer chains by addition of multivalent ions, e.g. of calcium, magnesium or zinc, but especially of aluminum and the elements of the 4th subgroup, titanium, zirconium and hafnium. Aluminum only occurs as a trivalent ion; as regards the elements of the 4th subgroup, the stable oxidation state +4 is employed.

In this way it becomes possible to postpone the conversion of the bed of threadlike polymer chains into a no longer flowable three-dimensional network until the drying from a solution is carried out.

To be able to use the metal ions in mostly organic solvents on the one hand, and on the other hand to prevent a premature cross-linking reaction in the polymer solution, organic, low-molecular complex formers are employed to which the metal ions are initially bound. Among these complex formers, acetylacetone assumes a special role in the field of medicine, as it is of relatively uncritical toxicology and, in addition, can be readily removed from the product in drying processes.

Acetylacetone is, in its chemical enol form, a vinylogous acid and forms complexes with the metal ions - the corresponding acetylacetonates. These complexes are of their own chemical nature, with particular stability, and cannot be compared to common salts of organic acids with the respective metals.

Aluminum acetylacetonate and titanyl acetylacetonate are used to cross-link polyacrylate pressure-sensitive adhesives during drying from organic solvents.

In the course of the cross-linking, a transfer of the metal ions from the complex former to the functional groups of the acrylate polymer takes place, whereby several functional groups on different polymer chains are cross-linked.

With regard to the cross-linking reagents aluminum acetylacetonate and titanyl acetylacetonate, which are very frequently used with polyacrylates, it has now surprisingly been found that they have a practically identical effect, phenomenologically, when used with polysiloxanes, despite the fact that these have an entirely different chemistry: the flowability of silicone pressure-sensitive adhesives is significantly reduced.

The characteristics of this change in the case of polysiloxanes are so similar to those in the case of polyacrylates that one may assume that a three-dimensional cross-linking takes place - via a mechanism the details of which are not known.

The novel manner of cross-linking was tested on two groups of silicone pressure-sensitive adhesives that are of particular significance for medical application: on pressure-sensitive adhesives on the basis of polydimethyl siloxane, in a non-amine-compatible form on the one hand and on the other hand in an amine-compatible form.

The non-amine-compatible form is characterized in that a remainder of silanol groups (hydroxyl groups bound to silicon) remains in the polymer upon polymerization. This is the standard type which is capable of undesired reaction with primary, secondary or tertiary amine groups via the silanol groups.

As many pharmaceutical active substances contain amine groups, amine-compatible types are available especially for application in TTS. These are subjected to a so-called end-capping: the silanol groups are deactivated through suitable reagents, e.g. by addition of a trimethylsilyl group.

A pressure-sensitive adhesive on the basis of a polyacrylate with a low proportion of free carboxyl groups was used for comparison. The three-dimensional cross-linkability of such acrylates through the cross-linkers discussed here is commonly known to those skilled in the art.

The following formulations were examined:

cross-linker: Al-acetylacetonate [% Al ³⁺ (w/w)]	---	0.01	0.025	0.05
polyacrylate pressure-sensitive adhesive Durotak 387-2051	A11	A12	A13	A14
silicone pressure-sensitive adhesive Bio-PSA Q7-4602	S31	---	---	S32

cross-linker: Ti-acetylacetonate [% Ti ⁴⁺ (w/w)]	---	0.05	0.1	0.2
silicone pressure- sensitive adhesive Bio-PSA Q7-4602	S11	S12	S13	S14
silicone pressure- sensitive adhesive Bio-PSA Q7-4301	S21	S22	S23	S24

Al = aluminum; Ti = titanium

The indicated cross-linker concentrations relate to the dried adhesive mass.

Bio-PSA Q7-4602, produced by Dow Corning, is the solution of a non-amine-compatible pressure-sensitive silicone adhesive in ethyl acetate. Product 4301 differs from the above in that it is amine-compatible. The solvent used here is heptane. Durotak 387-2051, produced by National Starch, is the solution of a polyacrylate pressure-sensitive adhesive in a mixture of ethyl acetate and heptane without the addition of a cross-linker.

The adhesive masses were produced by adding the corresponding amount of a 2% solution of titanyl acetylacetonate in ethanol or a 4% solution of aluminum acetylacetonate in ethyl acetate to the adhesive solution and subsequent mixing.

The viscous adhesive solutions were spread in a thin layer onto a polyethylene terephthalate film (Hostaphan RN 100, produced by Hoechst) with the help of a suitable film-stripping frame and dried for 10 minutes at 80°C in an exhaust-air oven. For all formulations, the layer thickness was adjusted so that the resultant weight per unit area of

the dried film was $60 \text{ g/m}^2 \pm 5\%$. This corresponds to 6 mg/cm^2 and a layer thickness of approximately $60 \text{ }\mu\text{m}$.

With all of the tested pressure-sensitive adhesives, the coating onto polyethylene terephthalate results in a bond that can mechanically barely be dissolved. Alternately, the pressure-sensitive adhesive films were also, under otherwise identical conditions, produced on a carrier film equipped with a non-stick finish through coating with a fluorated polymer (ScotchPak 1022, produced by 3M). Under these conditions, the pressure-sensitive adhesive film can easily be mechanically removed from the carrier film and subjected to further processing.

The effects of the cross-linking additive were examined in the thus produced pressure-sensitive adhesive layers with two measuring methods, pertaining to apparatus:

The tack or tackiness of a pressure-sensitive adhesive describes its ability to spontaneously adhere to a surface.

This spontaneous tackiness, resulting after only an extremely short period of contact without any notable exertion of pressure, depends considerably on the flowability of the pressure-sensitive adhesive. A high flowability enables a rapid establishment of contact, covering the microstructure of a substrate surface in its entirety, and thus results in a high tack. Flowability is not the only characteristic determining the tack, but it is the most important.

The "rolling ball" method is a suitable measuring method for registering the tack. In this method, a ball made of a suitable material is provided with a starting speed and then let roll over the pressure-sensitive adhesive affixed to a planar carrier in a thin layer.

The distance after which the ball comes to a halt through the braking effect of the pressure-sensitive adhesive, which depends on the tack, can be evaluated, or else the time can be measured that the ball needs to cover a certain distance without coming to a standstill within this distance. The results of this second variation are not distorted by the often erratic course of the ball's "getting stuck".

The run time of the ball was measured on an inclined plane (glass plate with a strength of 1 cm) with an adjustable angle of inclination over a distance of 59 cm. With a defined preliminary distance of 17.5 cm, the ball was let roll onto the pressure-sensitive adhesive film, which was affixed to a polyethylene terephthalate film.

The run time was measured between two modulated infrared light barriers by means of a connected electronic timer with a display of 1/1000 seconds.

At an inclination angle of 35°, using a high-quality steel rolling-element bearing ball with a diameter of 18 mm, the run times shown in Fig. 1 were determined as the median values of 6 measurements each.

For all three types of adhesive, the measurements show a decrease in the run time correlated to the increase of the cross-linker concentration. Thus, the tack of pressure-sensitive silicone adhesives decreases through the addition of cross-linkers in a way as would have been expected, in theory, for a cross-linking and thus reduction of the flowability of the polymer, and as also becomes evident in the known example of the cross-linking of the polyacrylate (A11-A14).

This especially holds true for the non-amine-compatible silicone adhesive (S11-S14), but definitely also for the amine-compatible variety (S21-S24).

In addition, it becomes evident that the cross-linking is especially effective in the concentration range of up to 0.05% and also between 0.05% and 0.1% of aluminum.

The use of aluminum-based cross-linkers (S31+S32) instead of titanium-based ones (S11+S12) with silicone pressure-sensitive adhesives turns out to equally effective (Fig.2).

In addition, the shear strength of the produced pressure-sensitive adhesive films was tested.

If a shear force is applied to uncross-linked, threadlike, flowable polymers, a slow flowing of the film occurs. As long as the shearing is not too fast and the film does not tear, the application of a constant shear force results in an almost constant flow speed.

In the case of a three-dimensional cross-linking of the polymer chain, on the other hand, the viscous proportion is almost entirely lost, and only an elastic deformation can occur. An increase of the shear force finally leads to a mechanical tearing apart of the polymer structure up to a tearing apart of the entire film.

Thus, cross-linked and uncross-linked pressure-sensitive adhesive films show very different characteristics regarding their behavior upon shearing.

To examine this behavior, round cut-outs with a diameter of 12 mm were removed from the produced pressure-sensitive adhesive films. These round pieces of film were fixed between two strips of a polyethylene terephthalate film (Hostaphan RN 100, produced by Hoechst) as shown in Fig. 3.

After clamping this arrangement into a commercial tensile testing machine (universal testing machine 81803, produced by Frank, Weinheim), the shear force per time which was necessary to achieve a constant shear speed of 2.5 mm/min was measured.

The thus obtained force/time diagrams of 6 individual measurements each are shown in Figs. 4 to 7.

In the case of the polyacrylate serving as reference, in the uncross-linked state a constant shear force is established after a short time which must be applied to maintain the predetermined constant shear speed: the polymer flows (Fig. 4).

In the cross-linked state, on the other hand, the shear force rapidly increases under elastic deformation until finally, the elastic expandability of the film is exceeded and the film tears, whereby the shear force rapidly drops off towards zero (Fig. 5).

The silicon film without a cross-linking additive shows a behavior very similar to that of the uncross-linked polyacrylate film: here, too, under a certain shear force the predetermined shear speed is maintained under flowing. The necessary forces are simply situated at a higher level, and the "energy barrier" for transition from the state of rest to a flowing movement is more distinct than with the uncross-linked polyacrylate (Fig. 6). This could be related to the different chain lengths and different intermolecular interaction forces of both polymer types.

What is decisive, however, is the characteristic change of the course in a cross-linker-containing silicone film. Very similarly to the cross-linked polyacrylate, a shear force is established under elastic deformation which finally drops off towards zero upon tearing of the film (Fig. 7).

This is evident proof that the silicone pressure-sensitive adhesive film is no longer flowable after addition of the cross-linker titanyl acetylacetonate.